Rapid freezing for storage of sheep milk

The team of researchers working on the Rapid Milk Freezer project. From left to right: Prof Richard Archer, Prof Mohammed Farid, Jolin Morel, Dr Georg Ripberger

Introduction

It has been said that New Zealand's prosperity was "built off the sheep's back", but in recent years Bovine, ie cow Dairy has become New Zealand's largest agricultural earner.

Traditionally, the sheep industry in New Zealand has focused on the production of meat and wool. In recent years however, a small but rapidly growing sheep dairy industry has developed. The sheep dairy industry produces a high value product, with a wide range of possible applications.

In order to support the growth of this industry, a small team of researchers from Massey University (MU), The University of Auckland (UA) and GNS Science (GNS) are working to develop a rapid freezer suitable for use on sheep farms, to allow raw sheep milk to be stored for long periods without a loss of product quality. This has the advantages that milk can be collected from remote locations (previously deemed uneconomic), and allows small-scale farmers to sell their milk in batches, as often required by cheese makers. This gives farmers greater market power and allows them to establish a profitable sheep-dairy business almost regardless of location.

This work is part of the larger MBIE-funded Food Industry Enabling Technologies (FIET) research programme, which aims to develop technologies that will grow export earnings by $250M pa by 2026.

Scope of work

This project is aimed at developing a rapid milk freezer, suitable for on-farm applications, and taking it to the on-farm prototype stage. This involves understanding the effects of freezing on milk quality (with a focus on raw sheep milk in a New Zealand context) and using this understanding when designing and optimising the on-farm freezer. This is the focus of the MU and UA team while GNS is developing low ice adhesion surfaces that will assist operation of the freezer unit and reduce operational costs.

Sheep milk production

Globally, sheep milk accounts for about 1.3% of total milk production. Sheep produce much less milk each day than cattle. In New Zealand, dairy sheep produce approximately 1.5-2L of milk per day, with a total yearly production between 150-300L of milk. This is significantly lower than what is achieved in countries with more established industries such as Israel (up to 750L per season) or Germany (450-550L per season). The most popular dairy sheep breeds are the East Friesian, Awassi, and Lacaune. These production systems are much more intensive than those encountered in New Zealand..

The equipment used in milking, and the design of milking parlours, are adapted from those used in goat dairy and are widely available.

FIET Food Industry Enabling Technologies

Food Industry Enabling Technologies (FIET) is funded by the Ministry for Business, Innovation and Employment and its purpose is to support new process developments that have the potential to add significant value to our national economy. The programme has six partners, Massey University (the host), Riddet Institute, University of Auckland, University of Otago, Plant and Food and AgResearch. The Board is chaired by Dr Kevin Marshall, with Dr David Tanner, Professor Pare Keiha, Dr Peter Fennessy and Dr Mike Matthews as Directors. Funding is $18m over six years (2015-2021) and targets pre-commercialisation activities.

The FIET programme will undergo a mid-term review in late November. The purpose of this review will be to assess and select a suite of projects that could add value through processing. If you are interested in more information, then please contact either Dr Jo Kerslake, FIET Programme Director (j.i.kerslake@massey.ac.nz) or Professor Richard Archer, Chief Technologist (R.H.Archer@massey.ac.nz). Further information about FIET can be found at fiet.ac.nz.

Sheep milk nutrition

Sheep milk is higher in total solids than both cow and goat milks. This difference is due mostly to higher levels of fat and proteins in sheep milk. The lactose level is similar to those in cow and goat milks, and the ash level is slightly higher. The higher solids content means that cheese yields are higher with sheep milk.

Component	Goat	Sheep	Cow
Fat (%)	3.80	7.62	3.67
Solid-non-fat (%)	8.68	10.33	9.02
Lactose (%)	4.08	3.7	4.78
Protein (%)	2.90	6.21	3.23
Casein (%)	2.47	5.16	2.63
Whey Protein (%)	0.43	0.81	0.60
Ash (%)	0.79	0.90	0.73

Sheep milk has higher levels of some vitamins (vitamin A and vitamins B1-5), and some minerals (Ca, P, Mg and Fe)

Sheep milk's fat is higher in valuable medium-chain triglycerides, and may be more easily digested than the fat in cow milk due to the lower diameter of sheep milk fat globules.

Sheep milk is claimed to have a superior amino acid profile when compared with cow milk. Difference in the proteins between sheep and cow milk may mean that sheep milk is less allergenic; however this is still the subject of ongoing research.

Sheep milk products

Traditionally, sheep milk has been used to make cheeses, and this is still its main use. Sheep milk cheeses include Feta, Pecorino, Manchego and Roquefort. In New Zealand there are around 18 varieties of sheep milk cheese being produced by producers ranging from artisan cheesemakers to large commercial enterprises. Other food products made from sheep milk in New Zealand include yogurts, ice-creams, ready to drink products, fermented drinks such as kefir and, of course, fresh milk .

Sheep milk is also used in the manufacture of whole milk powders and infant formulas. The different allergenic profile of sheep milk is helpful to some people who are sensitive to cow milk. Non-traditional dairy products such as calcium chews, soaps and cosmetics have also been developed.

Sheep milk products are generally aimed at the premium end of the market, and towards high-value export markets. As a consequence, the farm-gate price for sheep milk is significantly higher than cow milk, on a milk-solids basis.

Sheep dairying in New Zealand

The New Zealand Sheep Dairy industry consists of approximately 16 producers as of 2017, with an annual growth of around 5 farms and 3000 ewes. These producers range in size from artisan cheesemakers with 40 ewes, to a large, vertically integrated, operation that milks 20,000 ewes and produces milk powder, infant formula, and a range of cheeses.

As can be seen in the figure on the facing page, the sheep dairy industry is spread throughout the country. The geographic dispersion of producers, the seasonal nature of milking, small volumes of daily production, long distances to processors and intermittent demand for large volumes of milk (to take advantage of economies of scale in processing) suggest that a method for long term storage of fresh milk would be beneficial to the industry.

Freezing— a method for long term storage

Milk has been frozen on farms previously to overcome the issues of seasonality, quantity, and market access. A common practice involves freezing the milk in 2 L bladders, which are then stored and transported for domestic use or exported to international markets (e.g. yoghurt and cheese manufacturers). This method however has its drawbacks. Frozen storage of milk can lead to a decrease in milk quality by several mechanisms

- The proteins in milk that has been frozen and then thawed can agglomerate and precipitate, leading to lower product yields and undesirable textures
- The milk fat globules can be damaged during the freezing process, leading to oiling-off, oxidation of fats, and off-flavours.

Consequently, the thawed milk becomes unsuitable for uses such as liquid milk, UHT or drying as powder or formula. Previous research, and current trials at MU demonstrate that the quality of freeze-thawed

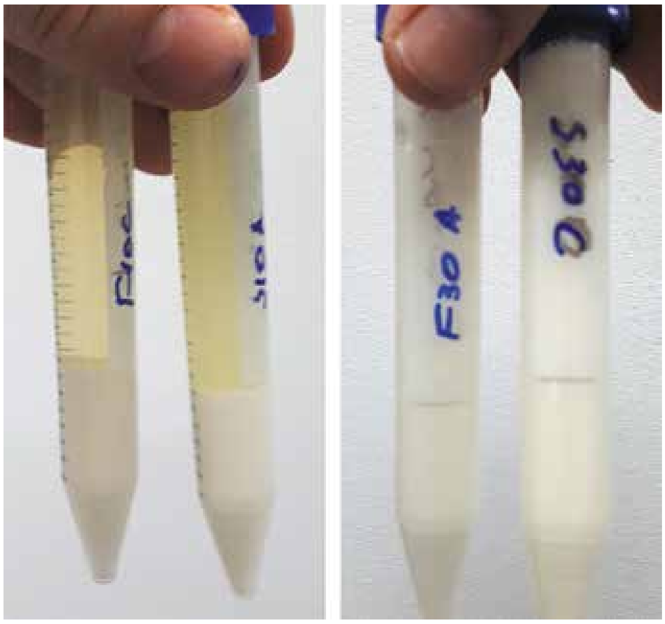

Figure 4: Sedimentation after centrifugation demonstrates that milk stored at -30 °C (right) is more stable than milk stored at -10 °C (left)

milk is dependent on a number of factors. The most important are the speed of freezing, the final storage temperature, and the duration of storage. Broadly speaking, the best quality is achieved when freezing is conducted as fast as possible, the frozen milk is kept as cold as possible (below -20°C), and the storage time is minimised.

Figure 4 illustrates the loss in protein stability that occurs during frozen storage at higher temperatures. Milk samples were stored at -10°C and -30°C for 9 weeks. After thawing at 20°C, the samples were centrifuged (3000 g x 60 min), and the amount of precipitate measured. It can clearly be seen that the proteins in the -10°C samples have precipitated, whereas they are still in the liquid phase in the -30°C samples.

The current practice of placing bladders or buckets of milk in blast freezers or refrigerated shipping containers counts as slow freezing (freezing times on the order of several hours), and is subject to handling issues (e.g. lots of manhandling and labour required).

Freezing is regarded as processing from a regulatory point of view. Thus, the unit operation of freezing has to take place in a food processing environment, and the normal on-farm dairy Risk Management Programme (RMP) must be extended to embrace processing and the premises be appropriately registered.

In this project a rapid freezer has been developed that mitigates the deleterious effects of traditional freezing methods, reduces labour costs, complies with the regulatory requirements, and enables ease of further processing.

Rapid freezing

Previous research suggests that the major causes of protein destabilisation are the physical aggregation of casein micelles after rejection from growing ice crystals, and the increased concentration of salts in the unfrozen phase. The damage to fats during freezing occurs due to physical aggregation of fat globules after similar rejection from the solid phase.

Rapid freezing, followed by storage at temperatures below -20°C should counteract these mechanisms. Work reported on freeze concentrators and falling film crystallisers shows that increasing ice growth rates increases the partition coefficient of the system, reducing the amount of solid rejected from the growing solid phase. The amount of a food product that remains unfrozen is also reduced at lower storage

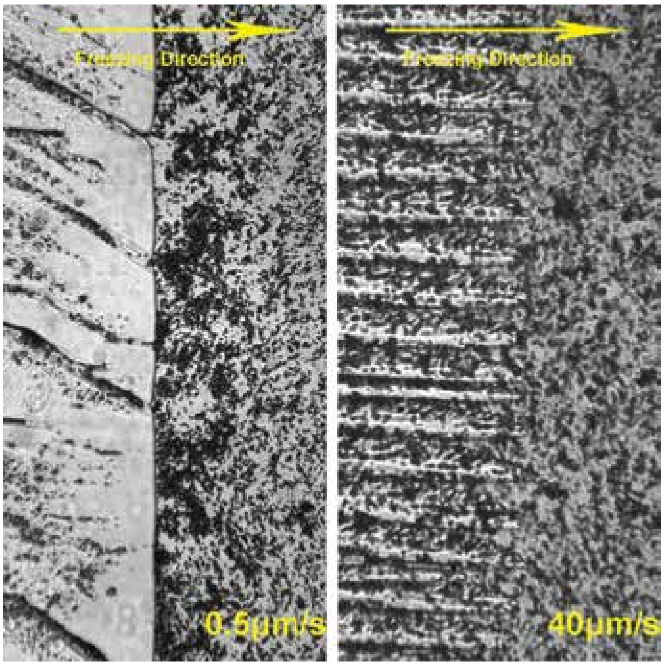

Figure 5: A freezing front in sheep milk at two different velocities (0.5 μm/s and 40 μm/s)

temperatures. This increases the stability of proteins during storage as it reduces their aggregation, reduces the amount of unfrozen phase in which destabilisation can occur, decreases the rates of any reactions occurring, and increases the viscosity of the remaining unfrozen phase, thereby further decreasing reaction rates. The damage to fats is also reduced, as the fat globules are entrapped by the growing ice front rather than being rejected.

Figure 5 demonstrates the differences between slow and fast freezing. Sheep milk was sandwiched between 2 sheets of glass in a Hele-Shaw cell, which was then placed in a Bridgman furnace, and the ice/milk interface was observed using transmission light microscopy. At low ice growth rates (0.5 μm/s) the interface is planar, and milk fat globules are rejected from the growing ice front, leading to an increased concentration in the unfrozen phase. At high freezing front velocities (40 μm/s), the growth is columnar with secondary branches growing at an angle to the main growth direction. At this speed fat globules are trapped within the advancing ice, and there is no concentration in the unfrozen phase.

The rapid freezer being developed operates by running a thin film of liquid milk over a cooled curved surface, onto which the ice freezes. Once the frozen milk layer has reached the desired thickness, the liquid flow is stopped and the adhered ice removed. The sheet of ice is then broken into flakes by an auger and transported to a storage vessel. This geometry is commonly used for flake ice for fisheries but lends itself to hygienic design.

In the system adopted the quality benefits of rapid freezing are combined with ease of handling to reduce labour requirements and allow for easier regulatory compliance. The thin flakes simplify subsequent thawing and give a product suitable for freeze-drying, should a processor desire this.

The technology may also enable processors to make raw milk cheeses, even if they are not located near sheep milk producers, as milk can be stored for extended times without thermal treatment.

Low-ice-adhesion surfaces

The key focus of the work being undertaken by GNS is the development of icephobic surfaces, i.e. surfaces with a low-ice-adhesion. The surface developed will be both food grade, and able to be applied economically to large surfaces. Readily available 304 stainless steel is the base substrate.

Locations of New Zealand sheep dairy farms

An icephobic surface will make it significantly easier to remove frozen milk from the heat transfer surfaces, with a minimum of heat or force. This will increase the thermal and mechanical efficiencies of the system, decrease cycle time and lower ongoing freezing costs.

Other applications

The hygienic flake freezing method and equipment developed can also be used to preserve in their native state without loss of functional value, other valuable, perishable liquid raw materials like blood plasma, whey and colostrum, that arise at times and places remote from existing central processing facilities. This allows the launch of new industries, which can secure and harvest their feedstock across New Zealand. It will also enable the development of new products like functional beverages (probiotics, ready-to-drink beverages) from niche raw materials like donkey and red deer milk, which have been shown to have bioactives.

Current progress and future plans

We have designed, built and instrumented a 50 L/hr pilot-scale unit that is currently commissioned. Our initial trials are on sheep milk but we would like to test other products as identified by businesses. Our next step in the development involves constructing and trialling an on-farm prototype of perhaps 250 L/hr capacity by mid-2018. We anticipate the on-farm unit might look like a refrigerated container with freezer, plant, controls and storage area inside, parked alongside the shed and fed by a pipe and a power cord. The detailed design is currently being carried out and we are working closely with MPI to comply with national and international regulations. And we are currently considering partners who might manufacture and market the units.